

# Development of coated conductors based on IBAD MgO

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Paul Arendt - MgO template development for coated conductors using ion-beam assisted deposition

Steve Foltyn - High current YBCO on IBAD MgO by pulsed laser deposition

\$1400 K, 4.5 FTE

*Superconductivity Technology Center  
Los Alamos National Laboratory*

# MgO template development for coated conductors using ion-beam assisted deposition

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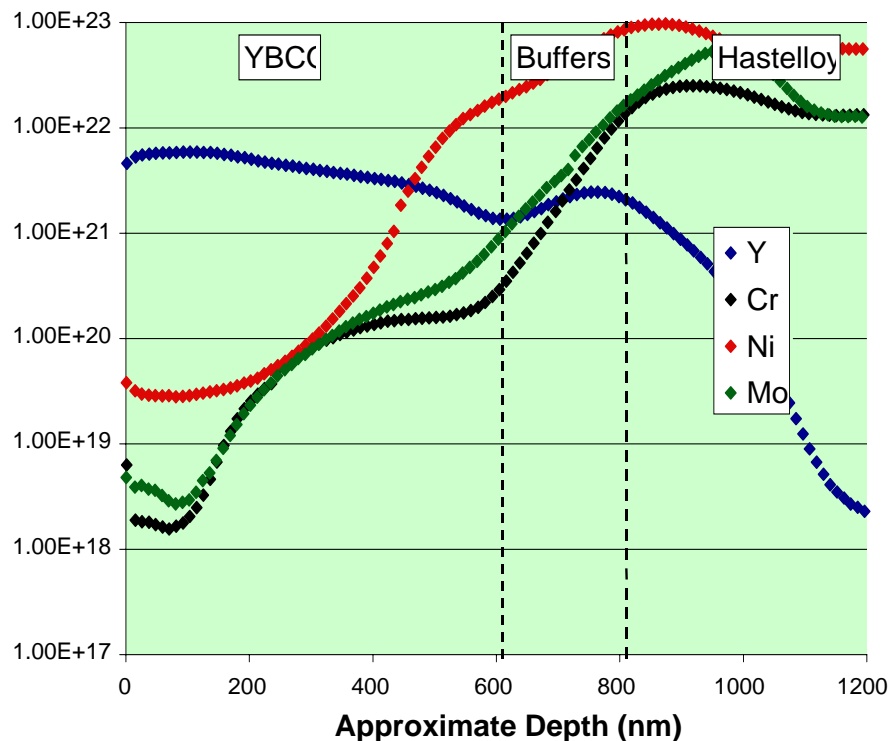
V. Selvamanickam, P. Hou, Y. Qiao, J. Reeves, X. Xiong

*IGC Superpower-LLC*

1. Substrate diffusion barrier
2. Transition metal effects on YBCO properties
3. MgO Ar<sup>+</sup> damage anisotropy measurements
  - a) damage dependency vs. dose and temperature
  - b) improvements in IBAD processing window

# Last year, a 70 nm thick “buffer” architecture of SrRuO<sub>3</sub>/IBAD MgO/Y<sub>2</sub>O<sub>3</sub> was found to be incapable of inhibiting diffusion of substrate elements into the final YBCO film

Secondary Ion Mass Spectroscopy (SIMS) revealed intermixing of the substrate and YBCO occurs



Diffusion of substrate elements is thought to be mitigated for IBAD YSZ with its thicker template/buffer architecture and for RABiTs with its thicker multilayer buffer stack.

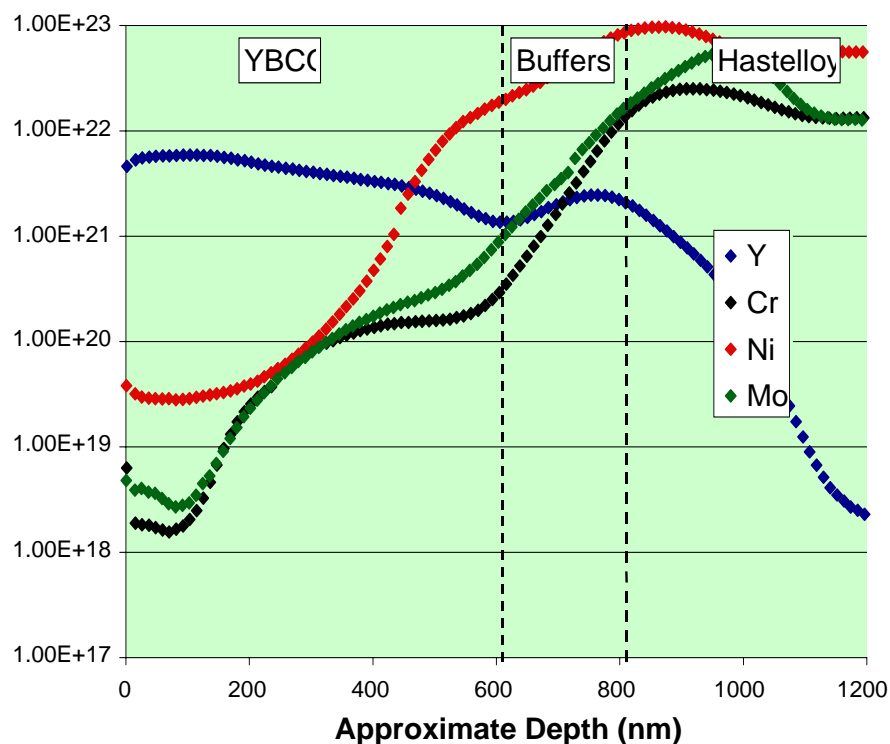
For IBAD MgO a comparable solution would be to employ thicker epitaxial layers between the template and the YBCO.

Another (more cost effective) solution could employ a barrier layer film below the IBAD MgO deposited near room temperature.

0.5μm YBCO/50nm SRO/12 nm MgO/7nm Y<sub>2</sub>O<sub>3</sub>/Hastelloy C-276

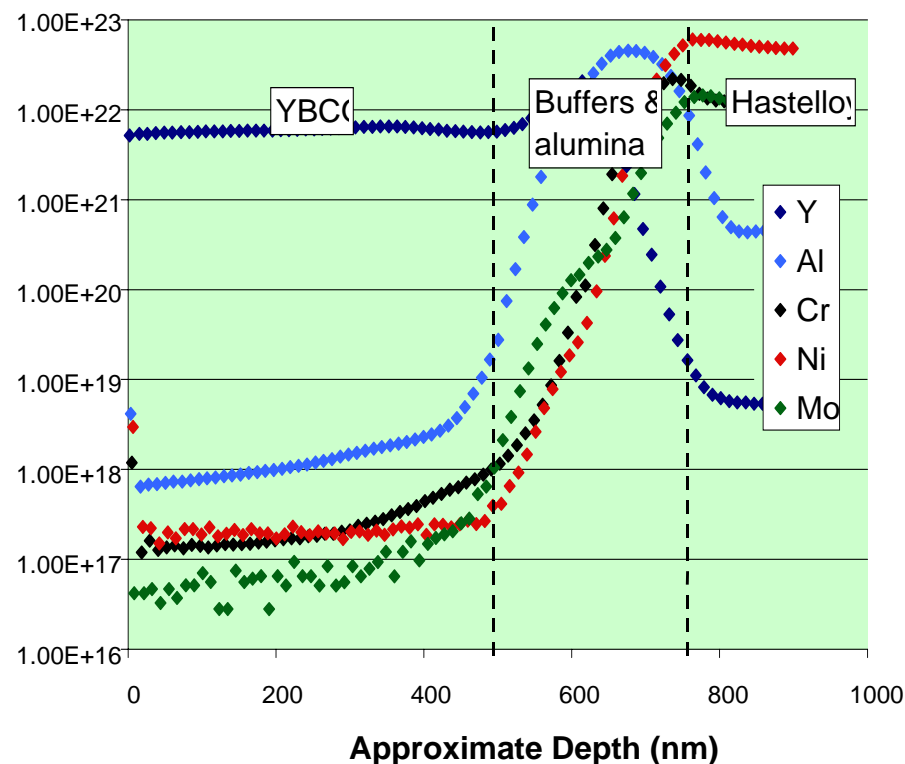
# $\text{Al}_2\text{O}_3$ films were shown to be capable of inhibiting diffusion of substrate elements

Secondary Ion Mass Spectroscopy (SIMS) revealed intermixing of the substrate and YBCO occurs



0.5 $\mu\text{m}$  YBCO/50nm SRO/12 nm MgO/7nm  $\text{Y}_2\text{O}_3$ /Hastelloy C-276

Inserting an 80 nm thick  $\text{Al}_2\text{O}_3$  film at the base of the buffer stack inhibited the intermixing

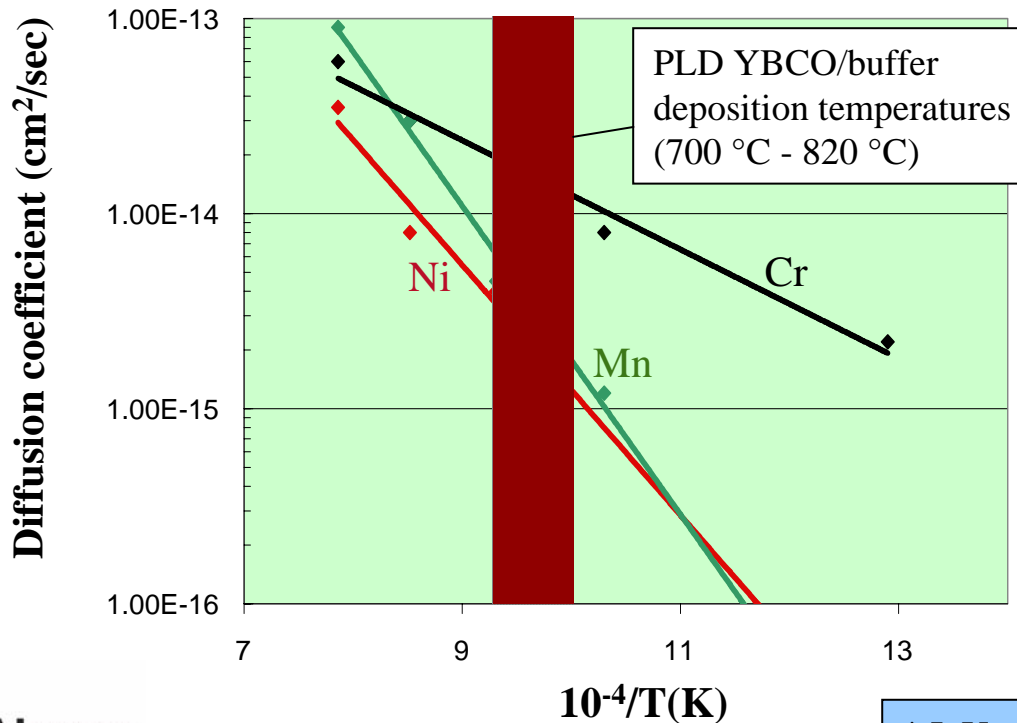


0.5 $\mu\text{m}$  YBCO/50nm SRO/12nm MgO/7nm  $\text{Y}_2\text{O}_3$ /80nm  $\text{Al}_2\text{O}_3$ /Hastelloy C-276

# A more detailed study was initiated to determine why this barrier worked\*

$\text{Al}_2\text{O}_3$  films deposited on Hastelloy C-276 were annealed at fixed temperatures from 500 to 1000 °C. Concentration profiles of the C-276 elements (C, Si, Mn, Co, W, Fe, Cr, Mo, and Ni) were then obtained in the  $\text{Al}_2\text{O}_3$  using SIMS.

Of the C-276 elements, only Mn, Ni and Cr were observed to diffuse into the alumina.

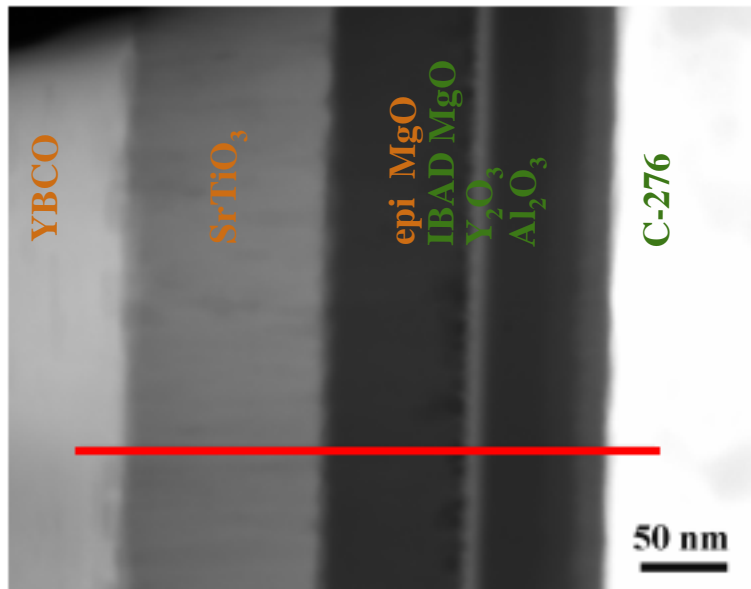


Based on the Arrhenius plot, after 10 min @ 850 °C,  $6 \times 10^{15}$  Cr atoms/ $\text{cm}^2$  will be on the surface of a 50 nm thick  $\text{Al}_2\text{O}_3$  film. ( $\approx 8$  ppm Cr in a 1  $\mu\text{m}$  thick YBCO film)

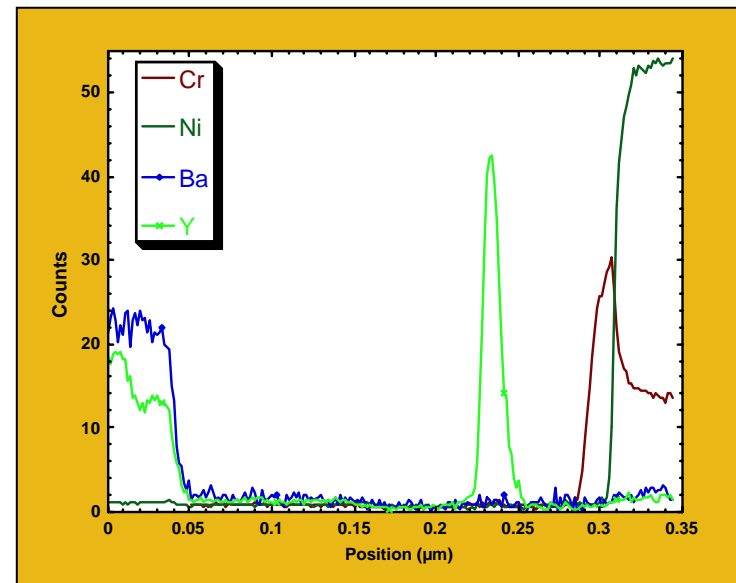
# Considerations to use of the diffusion coefficient data

Diffusion is a function of the source (element concentrations at the substrate film interface), film microstructure, etc.

Dark field TEM cross section of Superpower template (green) and LANL YBCO/buffers (orange).

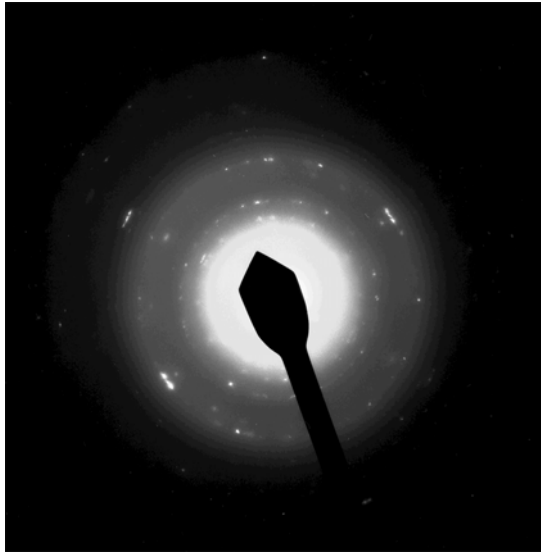


EDS line scan of Y, Ba, Cr, Ni.  
Cr is concentrated at the Substrate/ $\text{Al}_2\text{O}_3$  interface.

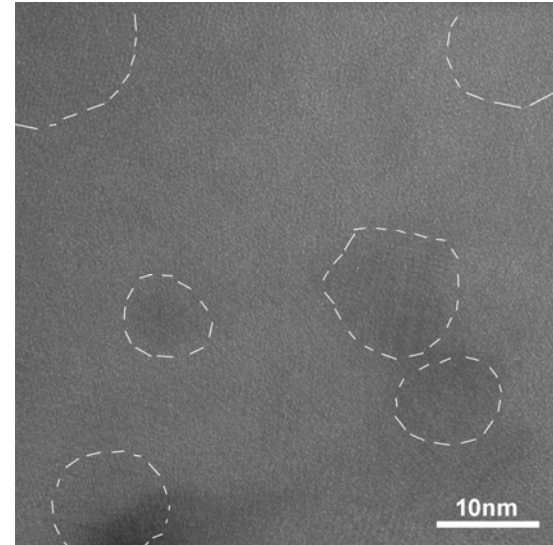


For a stainless steel substrate, Fe may play a role as one of the diffusing elements.

# Considerations to use of the diffusion coefficient data (cont.)



Selected area electron diffraction pattern of Al<sub>2</sub>O<sub>3</sub> film indicates it is amorphous and nanocrystalline



High resolution TEM image reveals the nanocrystallites are surrounded by amorphous material\*

An advantage of this microstructure is that the surface of the film is very smooth (< 1 nm Rms). Rutherford backscattering/Dektak analysis show the films are 83 % as dense as SXAL Al<sub>2</sub>O<sub>3</sub>. The diffusion coefficients in a polycrystalline film are expected to be higher.

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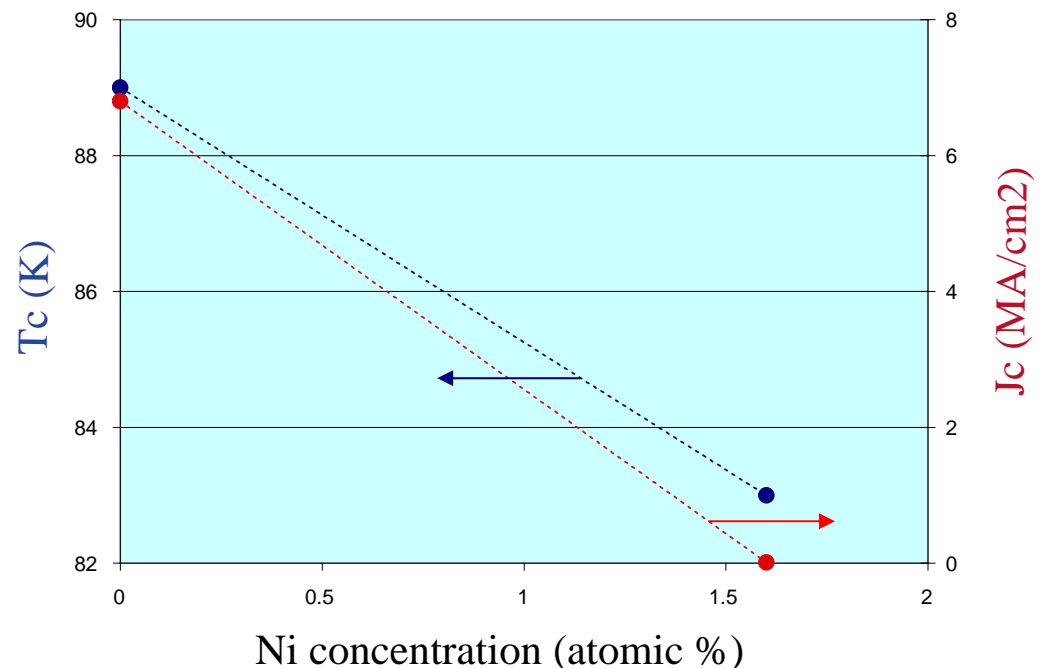
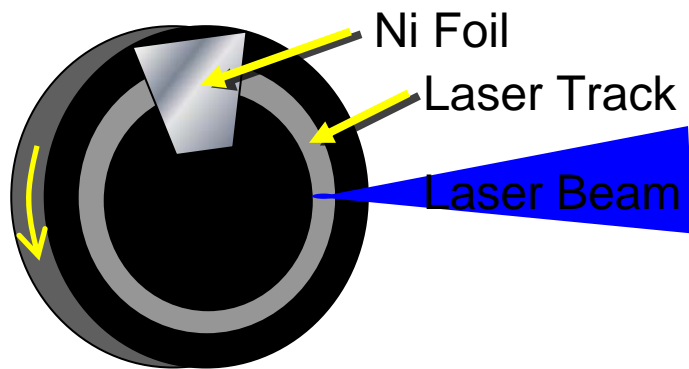
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# What is the quantitative tolerance of YBCO for some of the diffusing transition metals?

200 nm PLD YBCO films were deposited on SXAL SrTiO<sub>3</sub> substrates. The depositions were performed with and without a Ni foil strip mounted on the YBCO target.

T<sub>c</sub> and J<sub>c</sub> measurements were performed and the Ni concentration was measured using Particle Induced X-ray Emission (PIXE).



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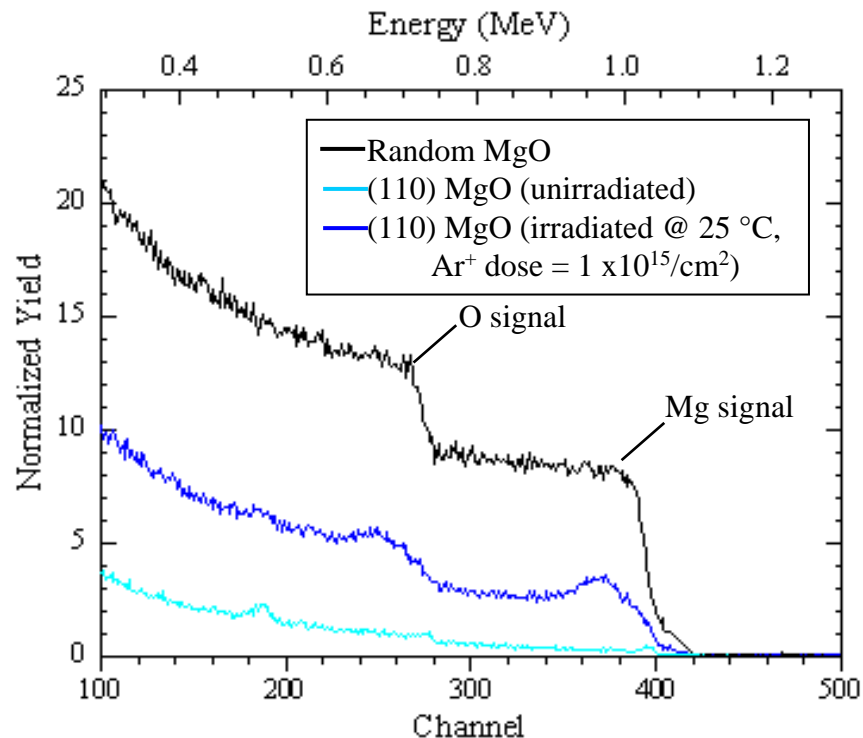
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# Damage anisotropy of Ar<sup>+</sup> irradiated MgO was investigated to elucidate an IBAD texturing mechanism

MgO single crystals of (100), (110) and (111) orientations were irradiated with 100 keV Ar<sup>+</sup> ions at varying doses and implantation temperatures.

Rutherford backscattering spectrometry (RBS) combined with ion channeling was then used to quantify radiation damage as a function of crystallographic orientation, ion dose and temperature.

RBS spectra of random and aligned (110) MgO samples.



# Damage anisotropy of Ar<sup>+</sup> irradiated MgO was investigated to elucidate an IBAD texturing mechanism

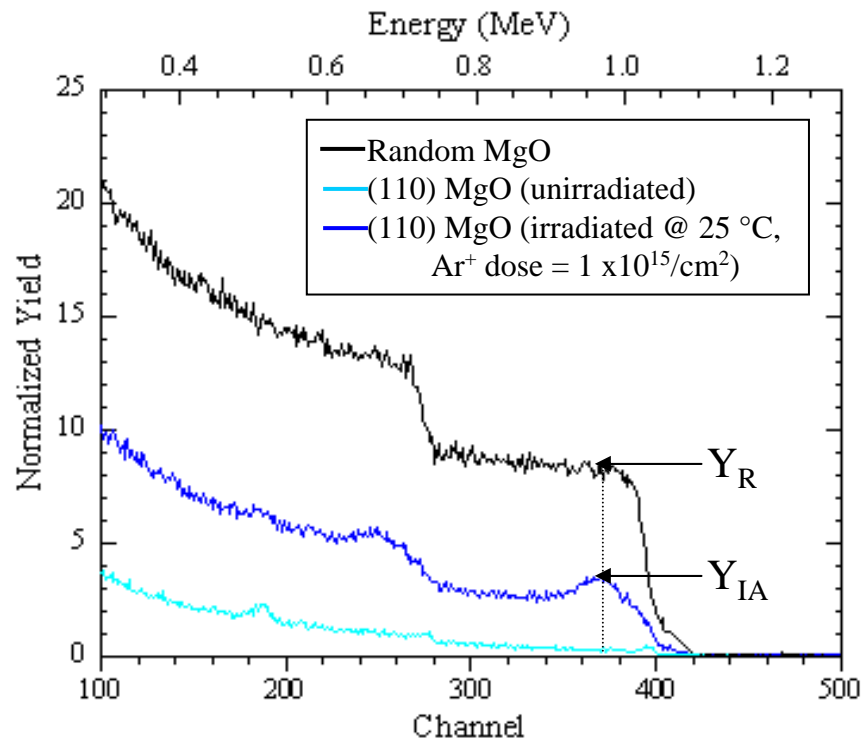
MgO single crystals of (100), (110) and (111) orientations were irradiated with 100 keV Ar<sup>+</sup> ions at varying doses and implantation temperatures.

Rutherford backscattering spectrometry (RBS) combined with ion channeling was then used to quantify damage accumulation as a function of crystallographic orientation, ion dose and temperature.

RBS spectra of random and aligned (110) MgO samples.

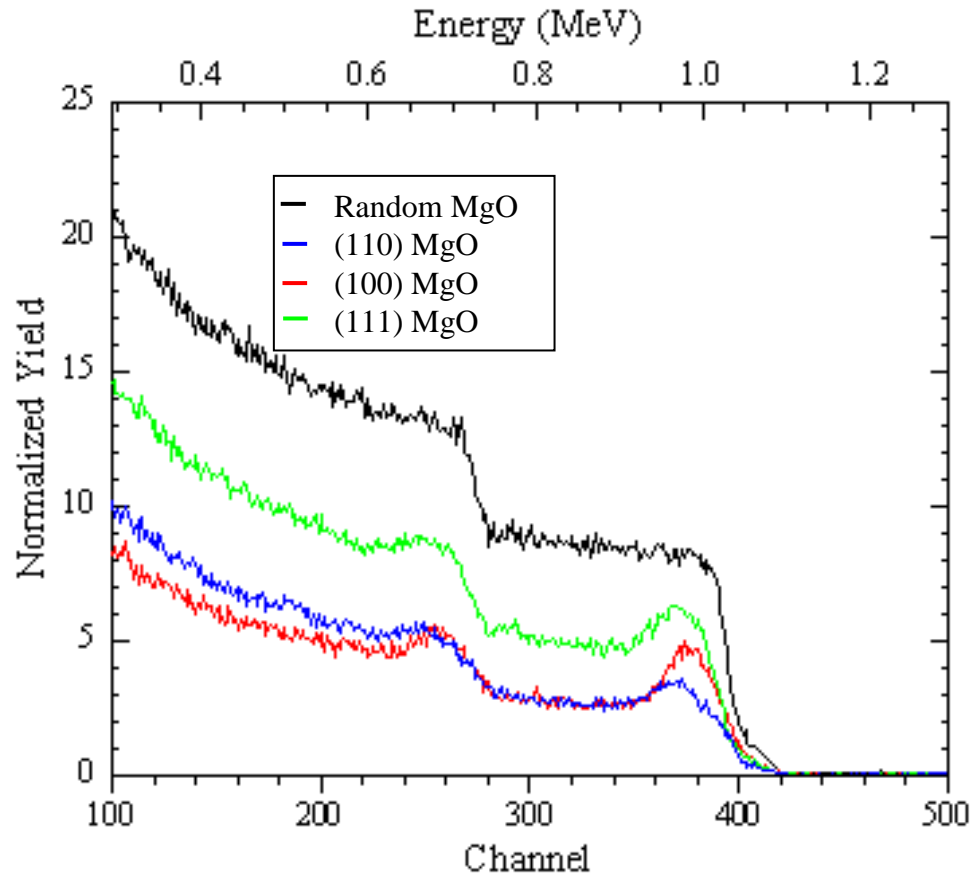
The damage is estimated using:

$$\chi_{\max}^{(110)} (\%) = Y_{IA}/Y_R$$

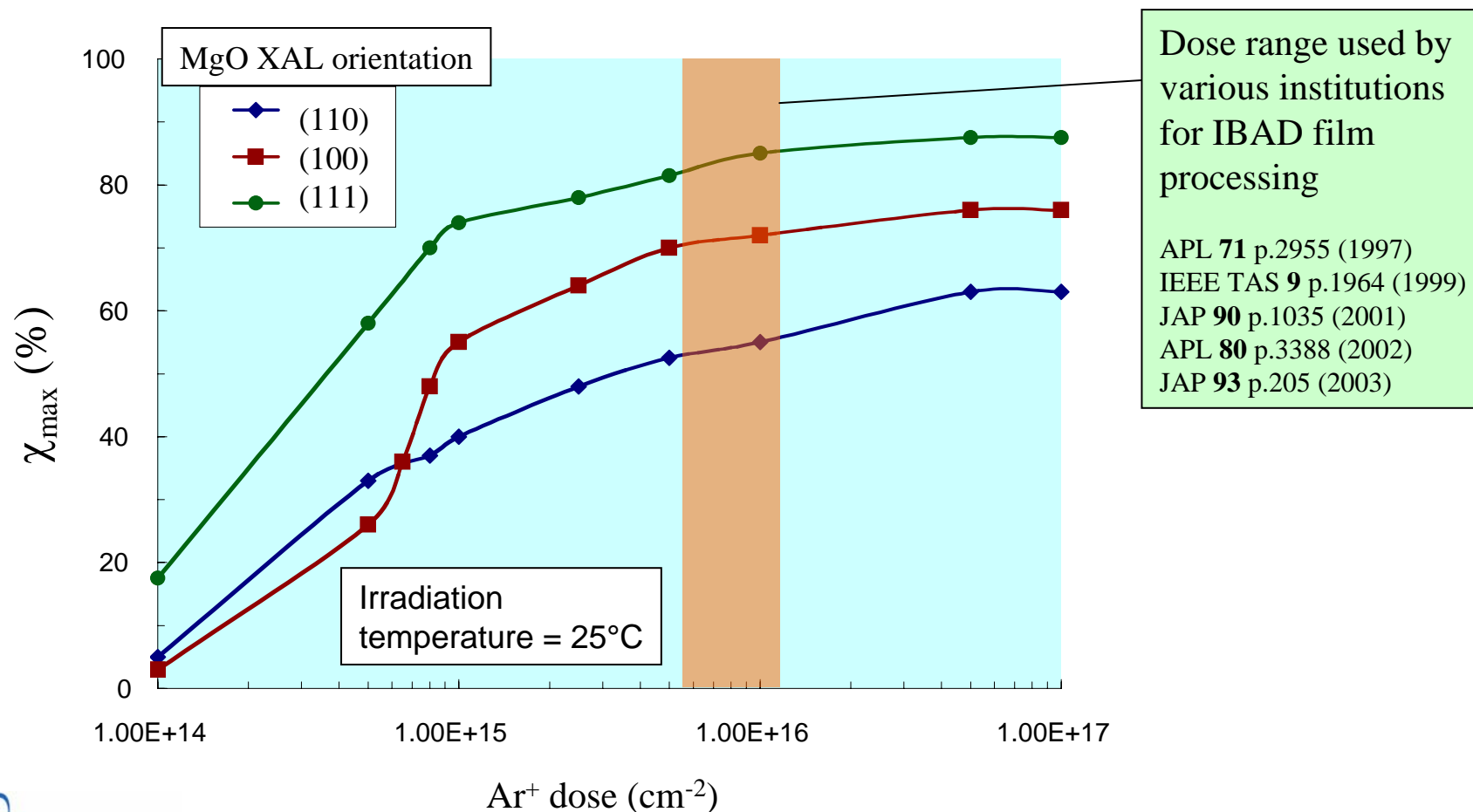


The measured damage exhibited by the different crystallographic orientations generally conformed to:  $\chi_{\max}^{(110)} < \chi_{\max}^{(100)} < \chi_{\max}^{(111)}$

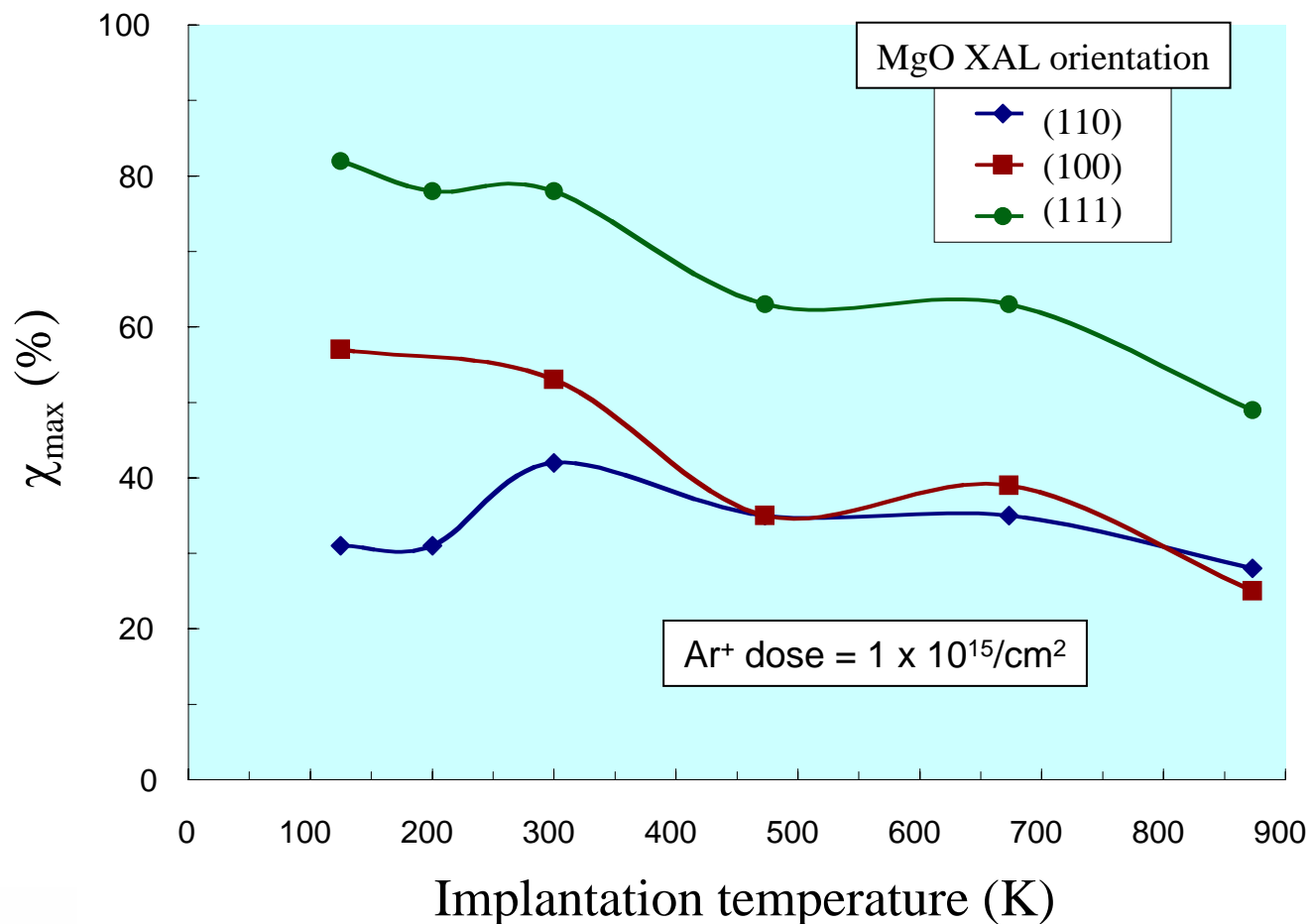
MgO crystals irradiated @ 25 °C, Ar<sup>+</sup> dose = 1 x 10<sup>15</sup>/cm<sup>2</sup>



# The difference in damage accumulation was relatively constant after the $\text{Ar}^+$ dose exceeded $1 \times 10^{15}/\text{cm}^2$



# The difference in damage accumulation for the three orientations was greatest at temperatures $\leq 200$ K

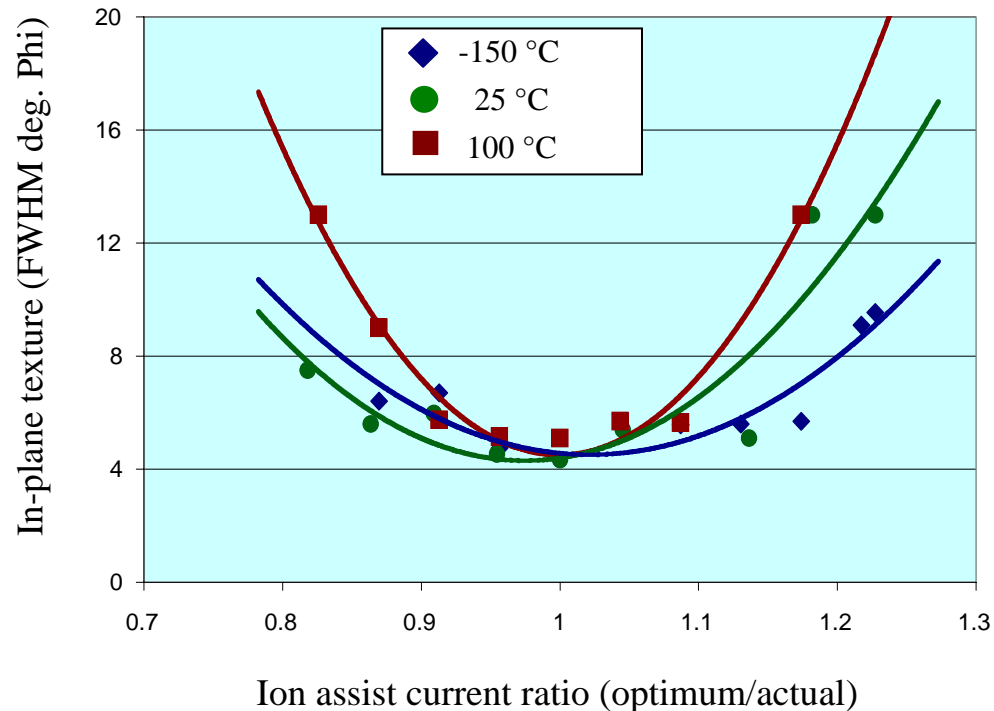


# The IBAD MgO processing window is expanded at lower film growth temperatures

Stationary substrates were held at fixed temperatures by silver pasting to a copper block during deposition.

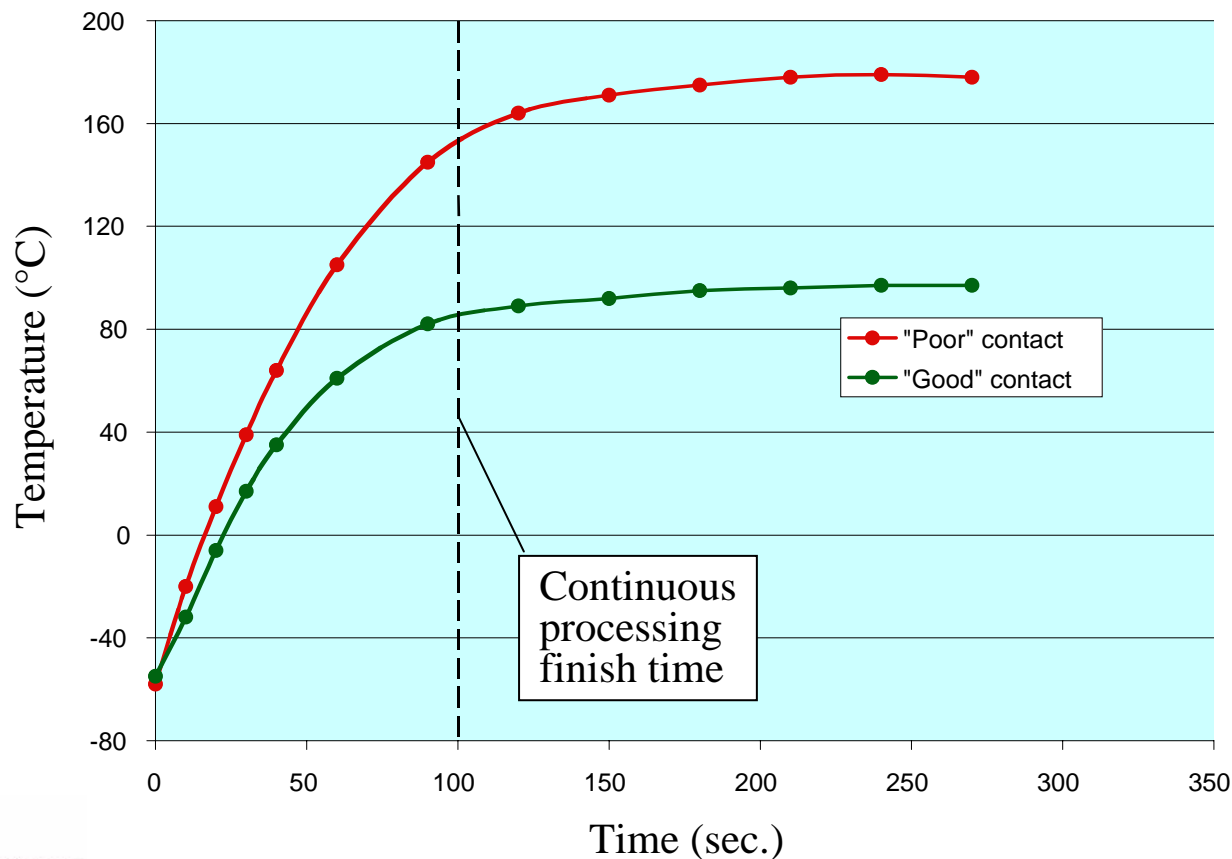
Many IBAD samples were made at three temperatures (100 °C, 25 °C and -150 °C) and at differing ion assist currents.

The processing window for obtaining  $\Delta\phi \leq 8^\circ$  is expanded by 40 % when going to 25 °C from 100 °C.



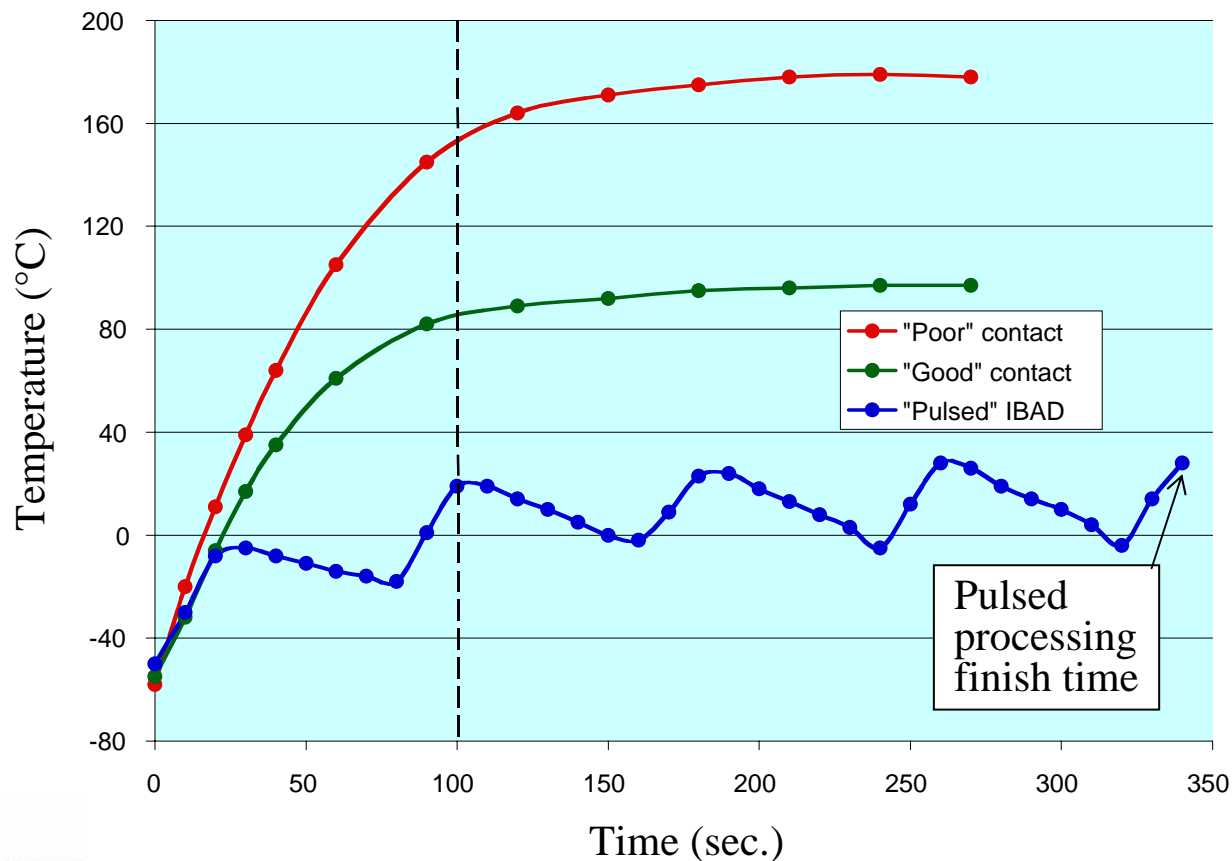
# Tape temperatures vary with the care taken to make good contact to the substrate cooling block

Surface temperature of 50  $\mu\text{m}$  thick C-276 tape heated by ion-assist gun conditions resulting in well textured IBAD MgO film in 100 sec.



# A desirable substrate temperature can be maintained by “pulsing” the IBAD deposition

Surface temperature of 50  $\mu\text{m}$  thick C-276 tape heated by ion-assist gun conditions resulting in well textured IBAD MgO film in 100 sec.



# Using lower deposition temperatures, we expect the IBAD texture to improve

To date: we have fabricated meter-length tapes at temperatures  $> 100^\circ\text{C}$ .

